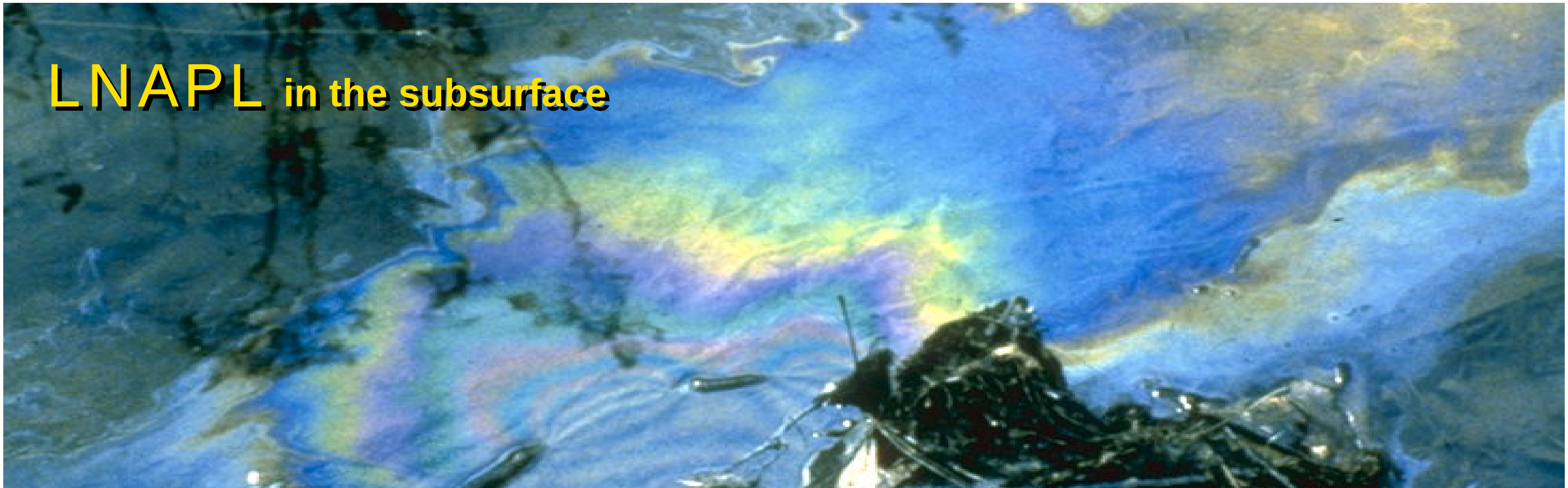
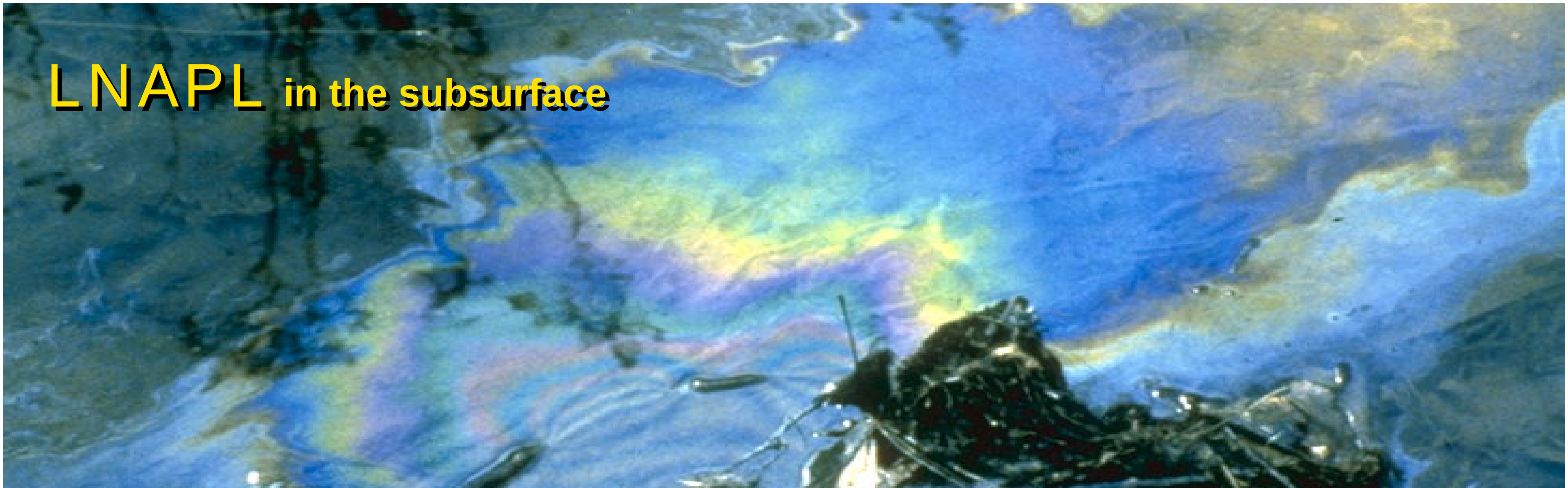


Developments in LNAPL Understanding

Randall Charbeneau, P.E.
Professor of Civil Engineering, University of Texas
Austin, TX USA

&

Mark Adamski, P.G.
Technical Specialist and Environmental Business Manager, BP America
Houston, TX USA



LNAPL Basics

Randall Charbeneau, P.E.
Professor of Civil Engineering, University of Texas

&

Mark Adamski, P.G.
Technical Specialist and Environmental Business Manager, BP America

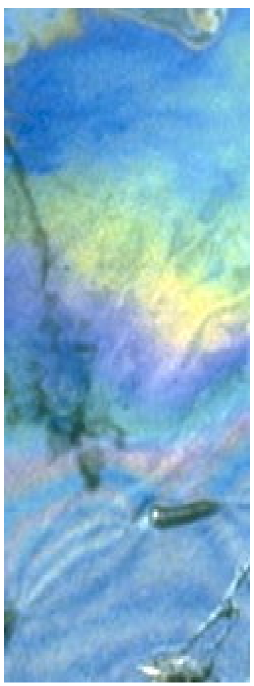
Ground Rules

Try to keep it light and fun

Ask questions!

If you don’t ask questions - we will

BP always reserves the right to say “Mark who? Never heard of him”



Credit – US EPA RTDF, ITRC LNAPL work group, more recently ITRC

US EPA Remediation Technology Development Forum (RTDF)

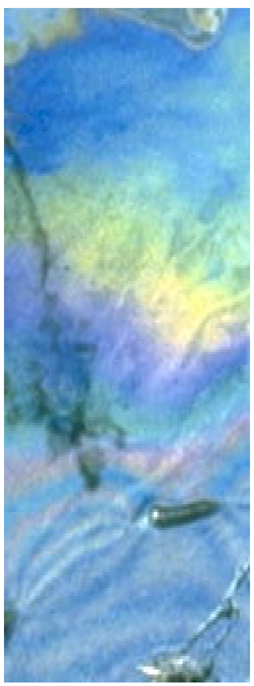
Interstate Technology & Regulatory Council

Andrew Kirkman of ENSR

Gerry Becket of Aqui-ver

Tom Sale of Colorado State University

Many others who have worked on the RTDF and ITRC LNAPL efforts



Some real basics first - What Is LNAPL?

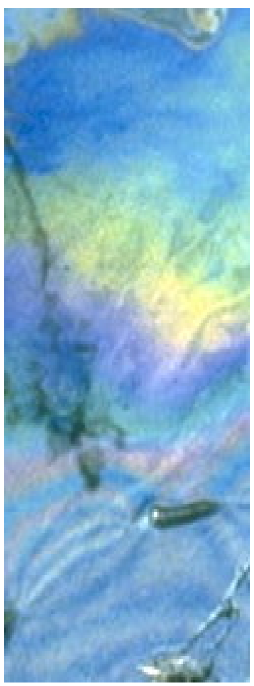
NAPL = Non-Aqueous Phase Liquid

- Includes chlorinated compounds and petroleum hydrocarbon products

<u>LNAPL</u> = NAPL that is less dense than water (generally petroleum hydrocarbon liquids, such as gasoline (petrol), diesel, jet fuel, crude, etc)

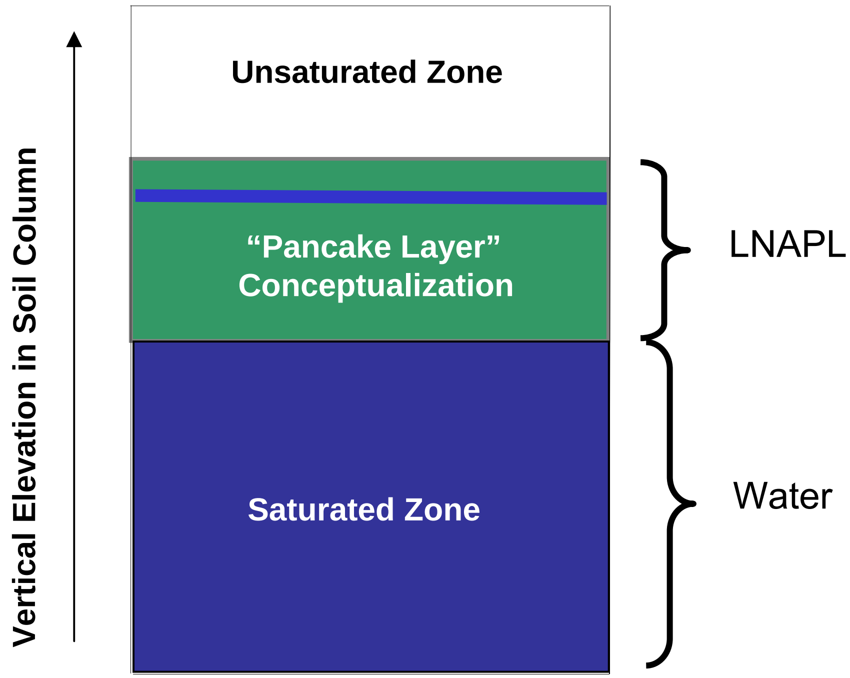
Common LNAPLs (petrol – are a mixture of many different compounds such as toluene, naphthalene, iso-octane, etc)

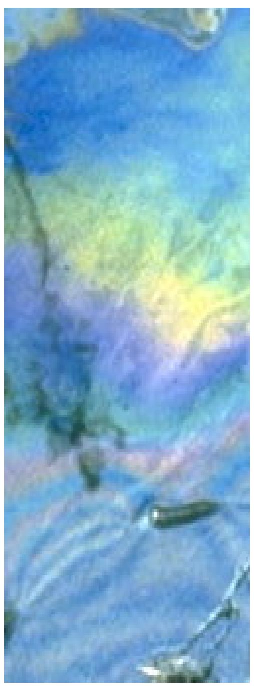
DNAPL = NAPL that is more dense than water (chlorinated compounds; not addressed in this course)



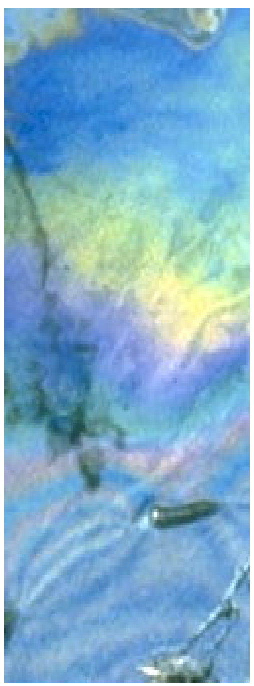
The conceptual understanding of LNAPL

1980's Pancake Model





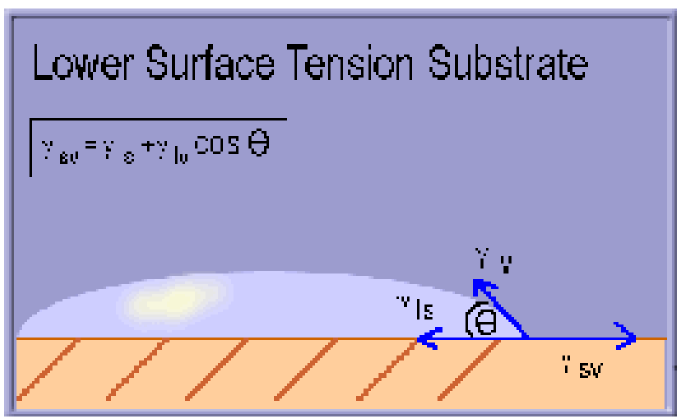
Wetting phase and non-wetting phase

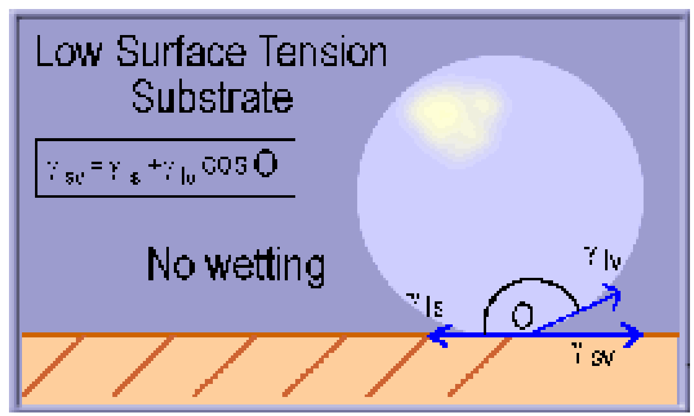


Important concept

Wetting phase means one fluid coats the surface of a solid preferentially to a second fluid

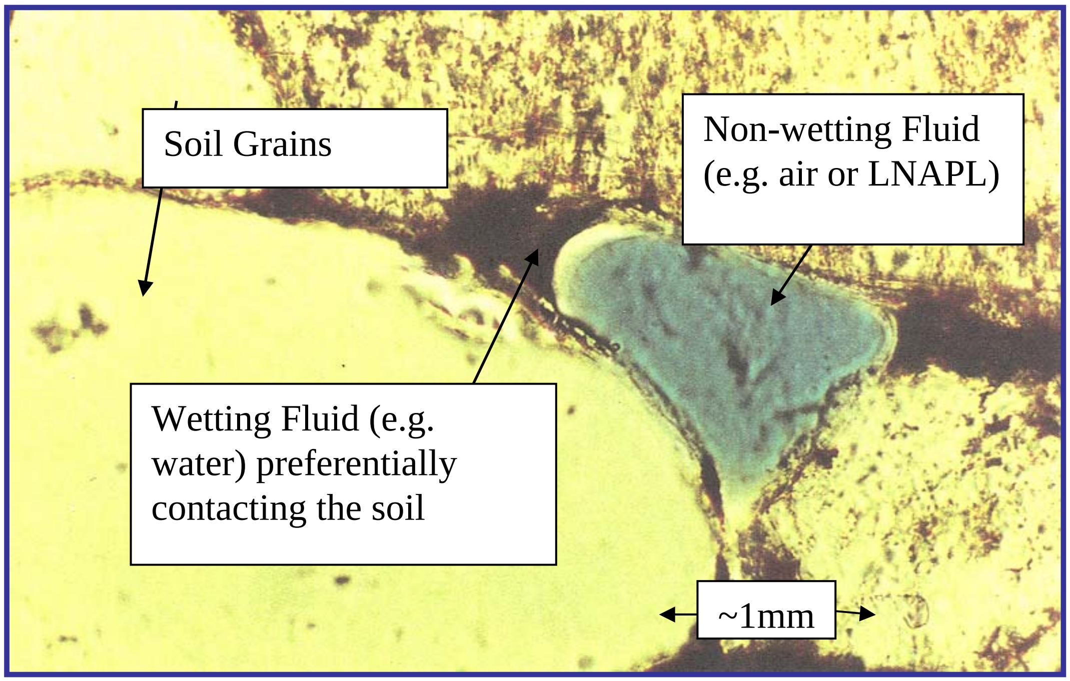
Common pairs:	Wetting Fluid:
Water / Air on rock	Water
Mercury / Air on concrete	Air
Water / Air on freshly waxed car	Air
Water / LNAPL on soil	Water



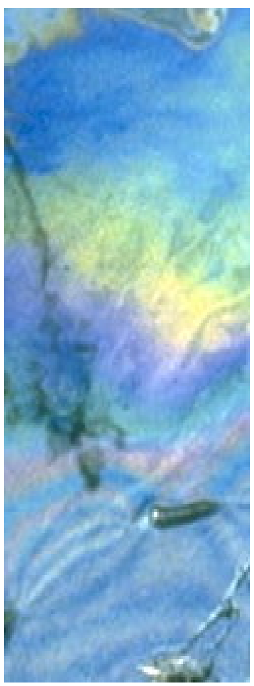


Phases

Porous media always contains multiple phases (solid, liquid water, liquid NAPL, and or, air:



Note: non-wetting fluid is in the big pore

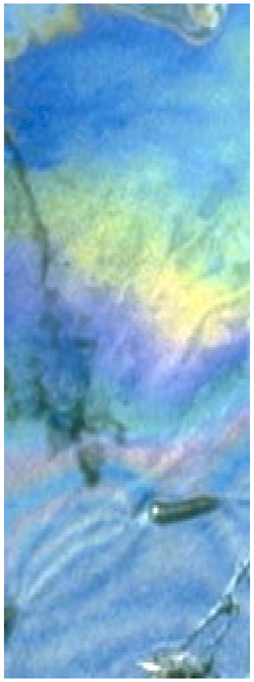


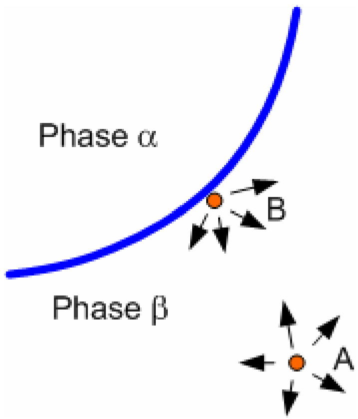
Surface or interfacial tension

Definition - Surface or interfacial tension - the force needed to oppose the natural pull of the molecules in the surface or interface to minimize the size of that surface or interface.

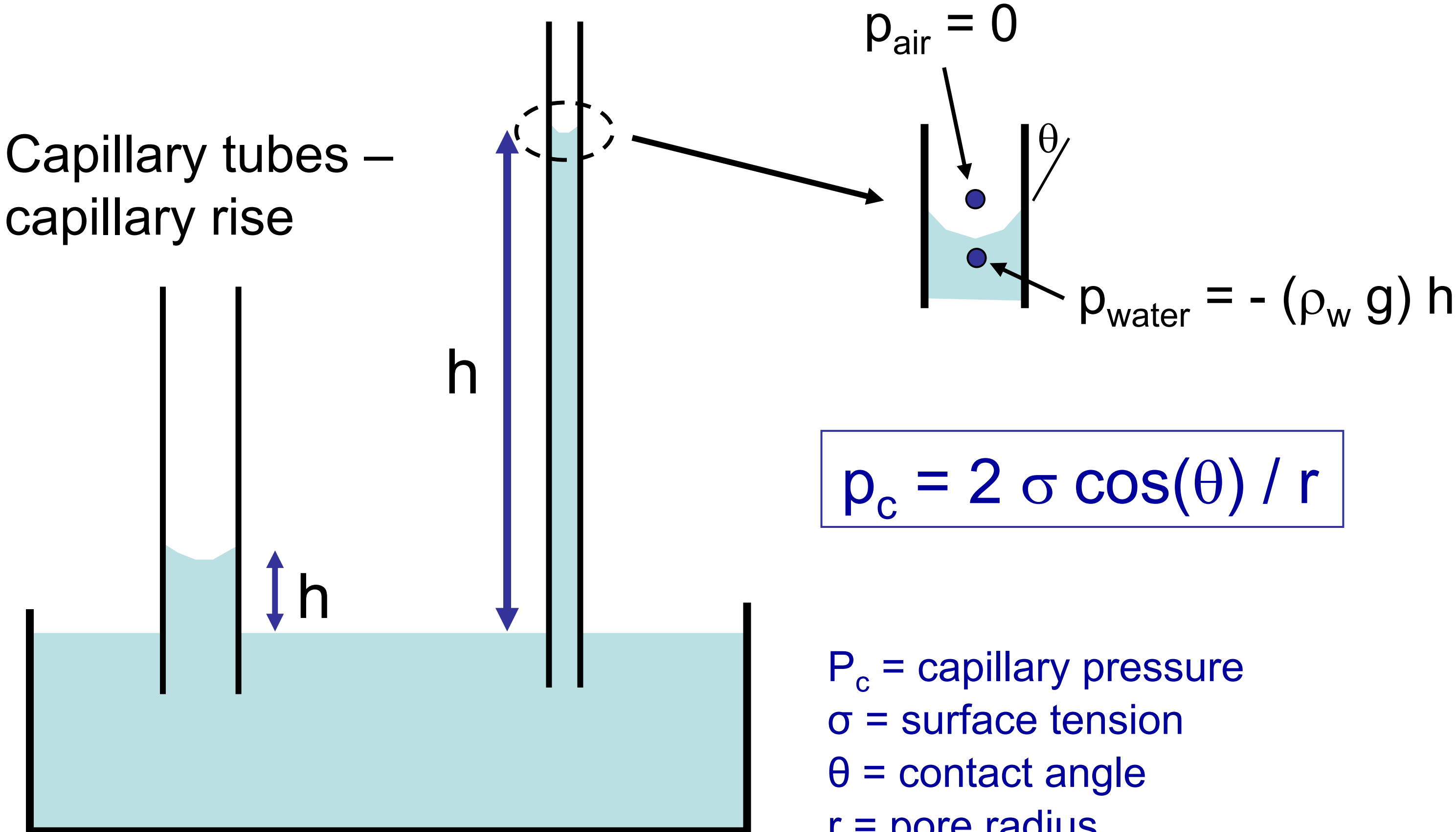
Results from the intermolecular attraction within a fluid

Oil and water has a considerable interfacial tension



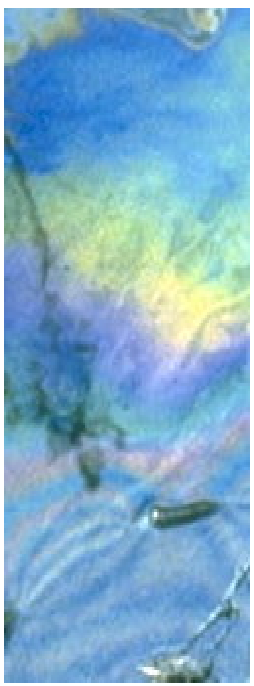


Capillary Pressure



$$\boxed{p_c = 2\ \sigma \cos(\theta) / r}$$

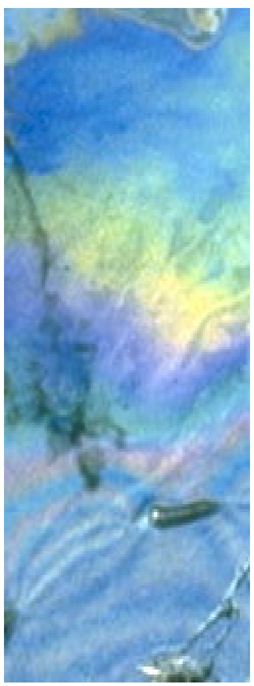
P_c = capillary pressure
σ = surface tension
θ = contact angle
r = pore radius
h = capillary pressure head
ρ = density
g = gravitational constant



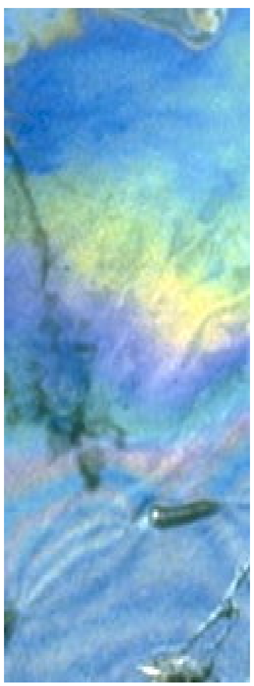
Saturation

The fraction of the pore space that is occupied by a given fluid phase is called the phase saturation.

$$\text{Saturation of water} = S_w = \frac{\text{volume of water}}{\text{volume of pores}}$$



Capillary pressure

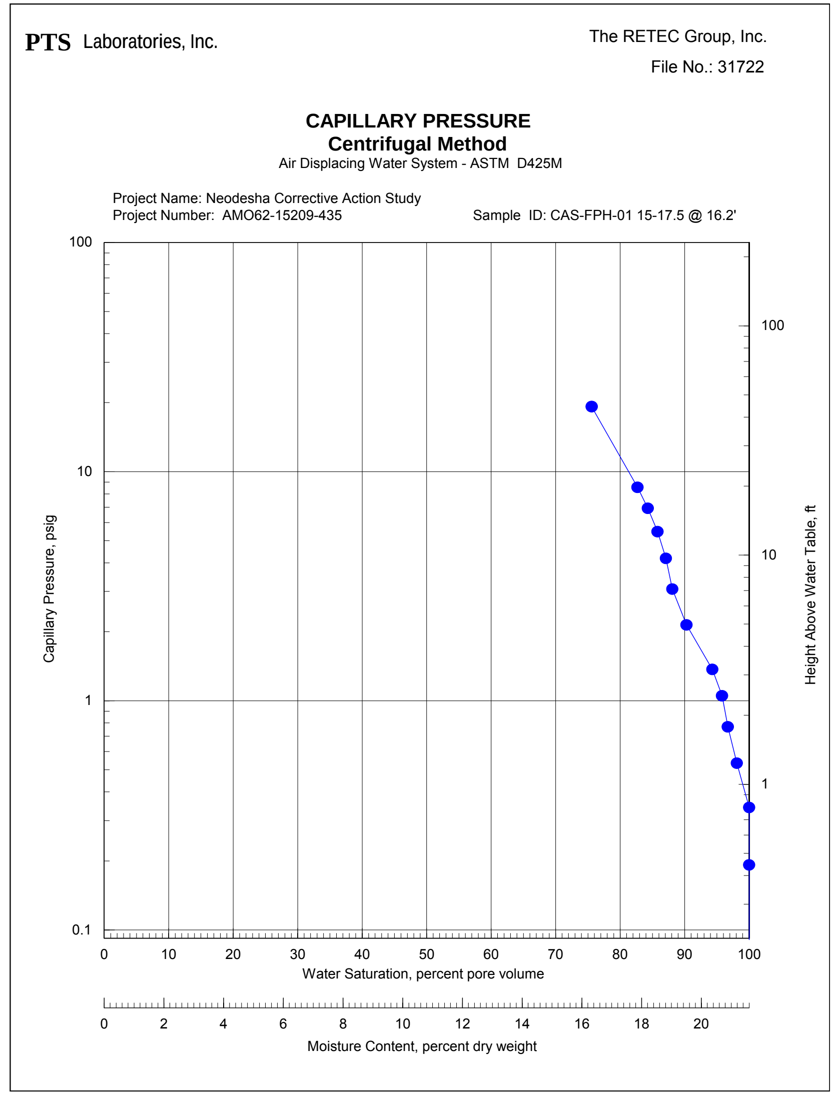


Is also defined as:

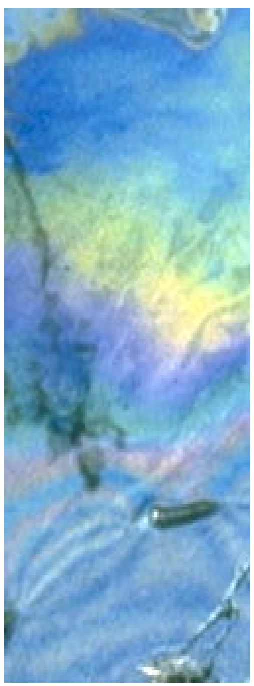
$$P_c = P_{nw} - P_w$$

high capillary pressure means:

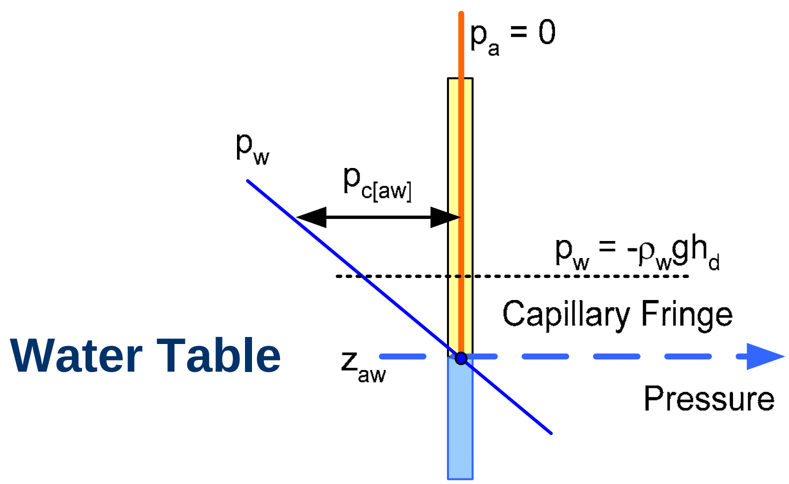
pressure non-wetting fluid >> pressure of wetting fluid



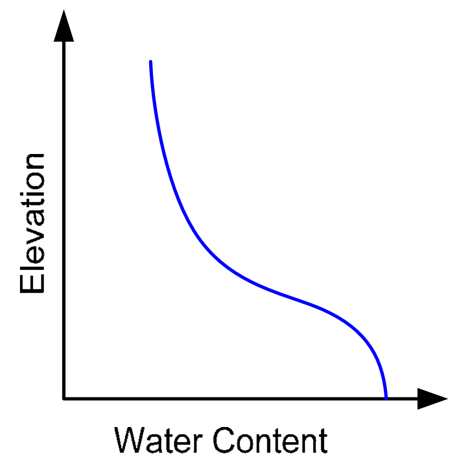
Water Pressure and Saturation



Capillary Pressure, p_c

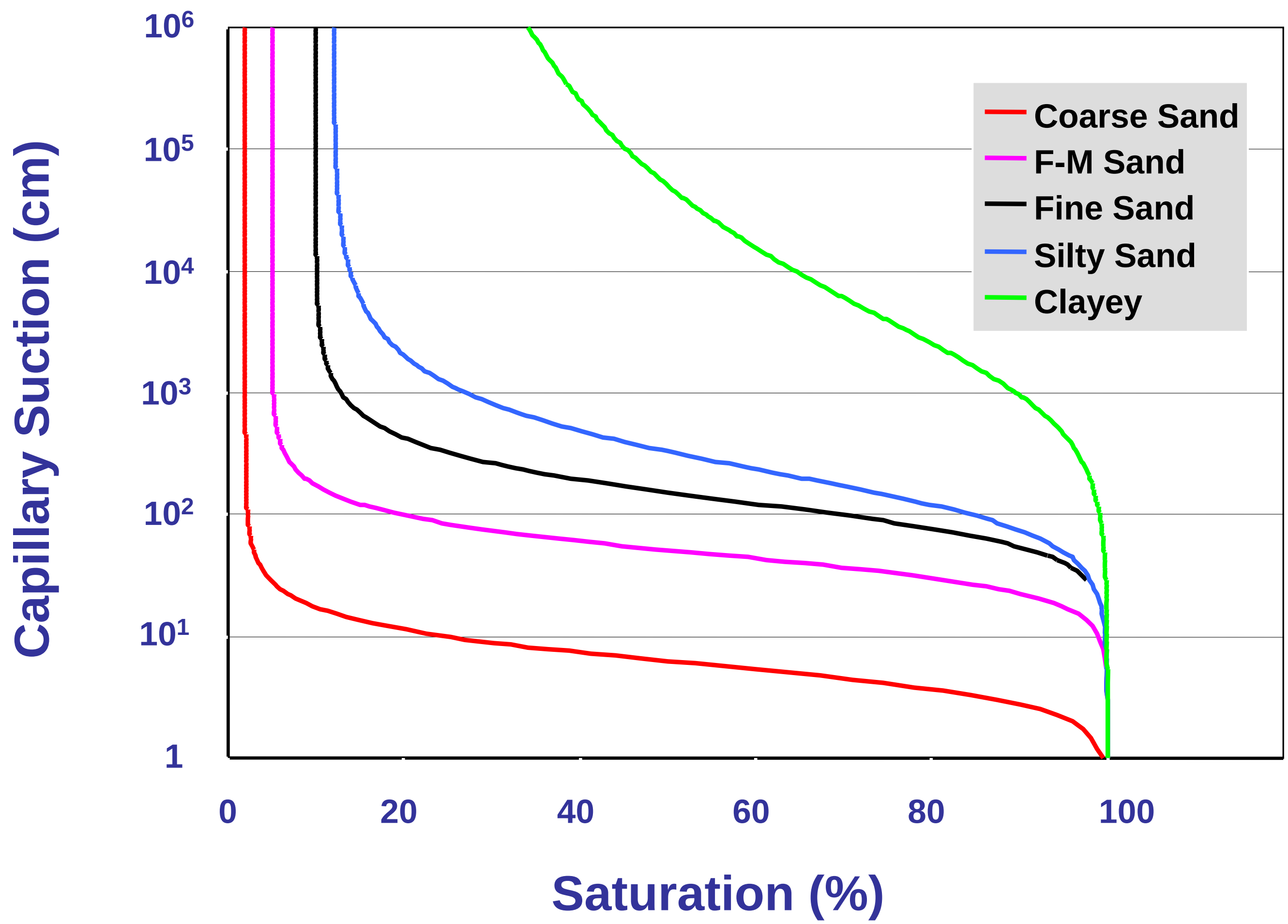


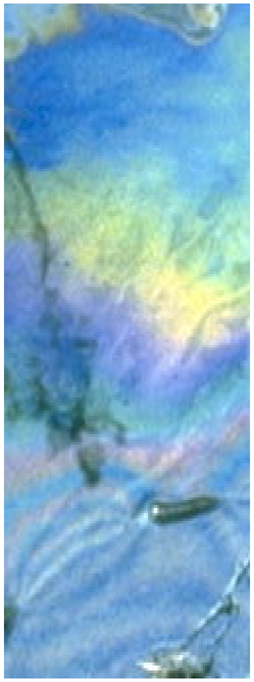
Water Saturation



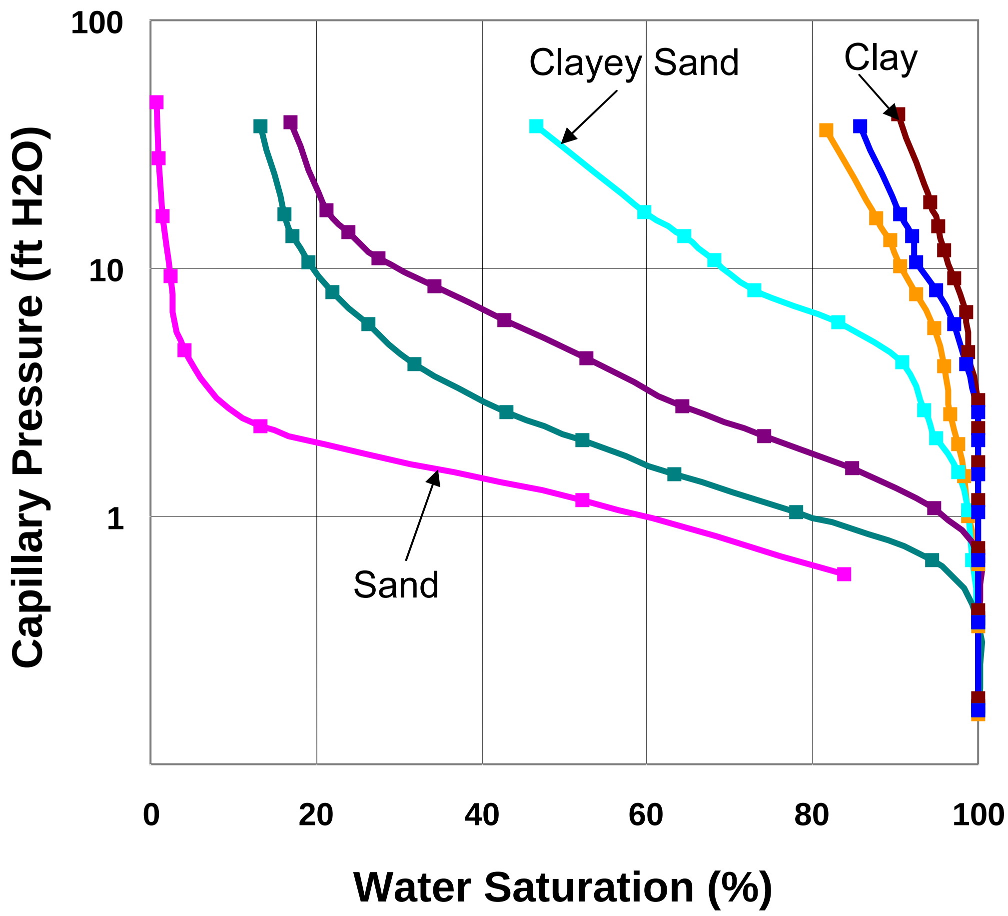
Hydrostatics: $dp_w/dz = -\rho_w g \rightarrow p_w + \rho_w g z = \text{constant}$

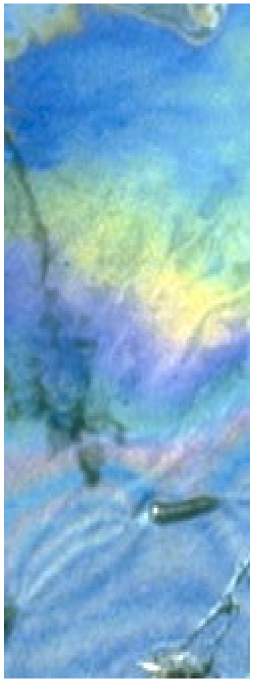
Idealized characteristic capillary pressure curves





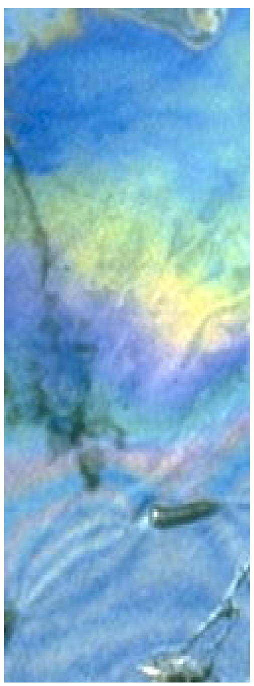
Measured capillary pressure (moisture retention) curves



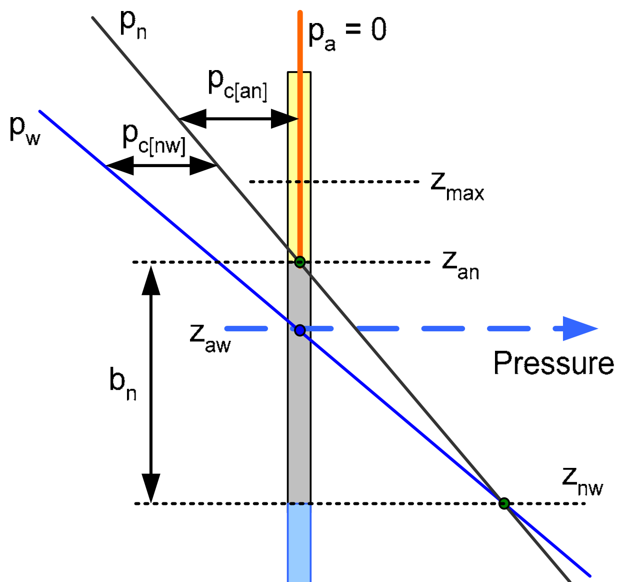


Fluid Pressures and LNAPL Saturation

LNAPL Accumulation near the Water Table



Capillary Pressures

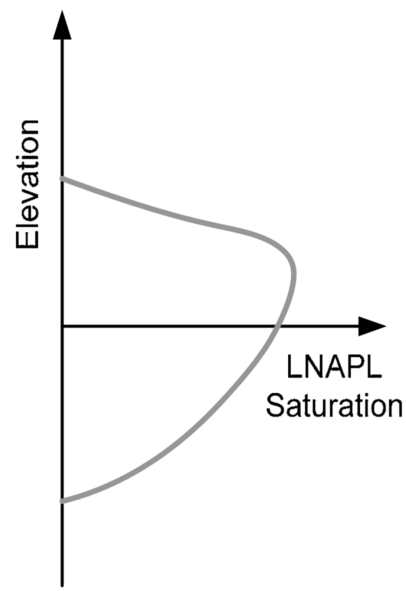


@ z_{aw}: $p_w = 0$

@ z_{an}: $p_n = 0$

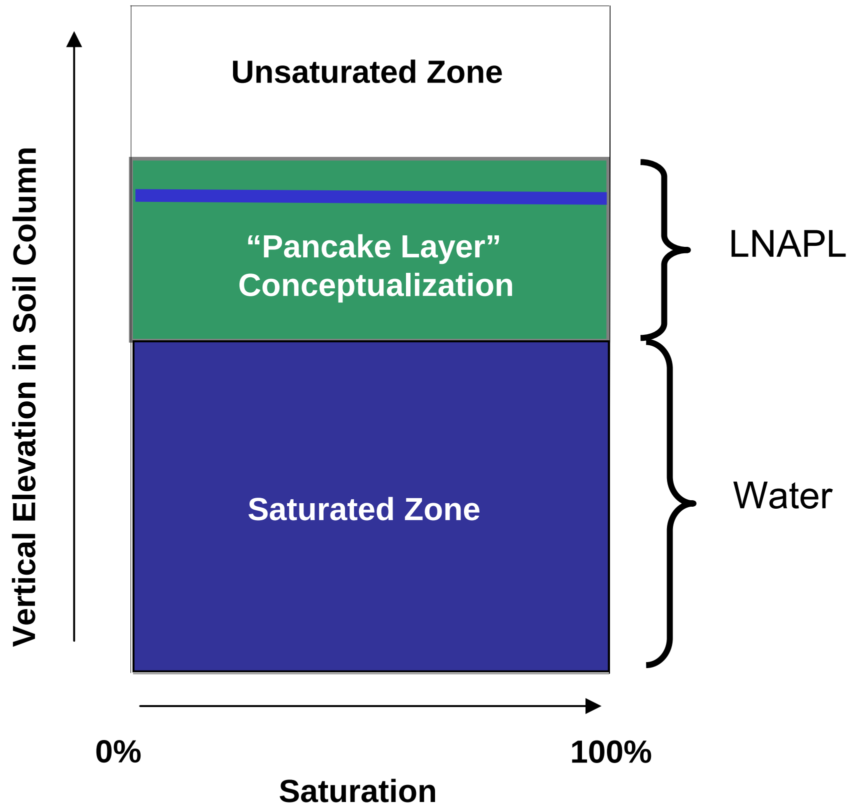
@ z_{nw}: $p_n = p_w \rightarrow p_{c[nw]} = 0$

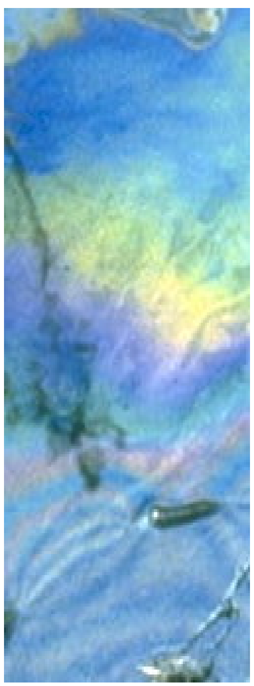
LNAPL Saturation



Does not include LNAPL residual saturation

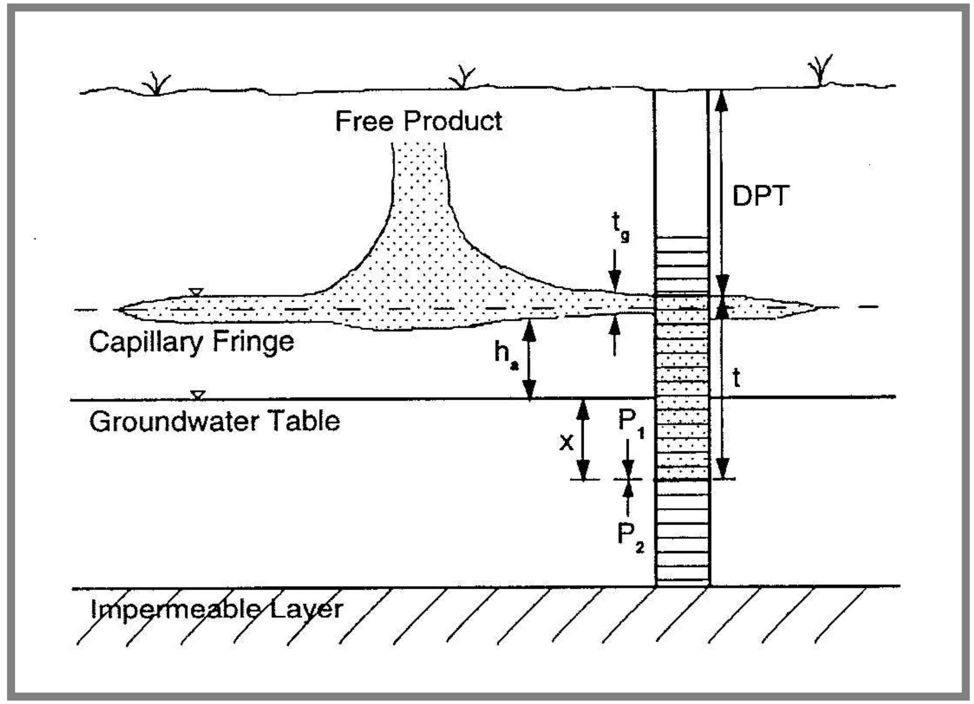
Remember the 1980s conceptual understanding of LNAPL?



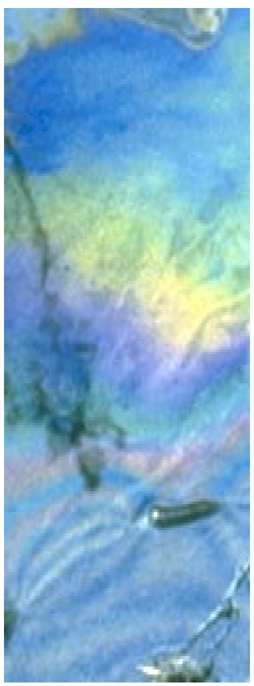


Origins of the classical conceptual model – "The Pancake"

- Ideal porous media "chosen for its uniformity" – using glass beads and the like (Ballestero et al. 1994)
- LNAPL floats on the WT or Capillary fringe (Van Dam, 1967)
- Oil enters well from top of capillary fringe (Van Dam , 1967)
- Thickness of gas in a well is 2-3 times that in the soil (Kramer 1982)

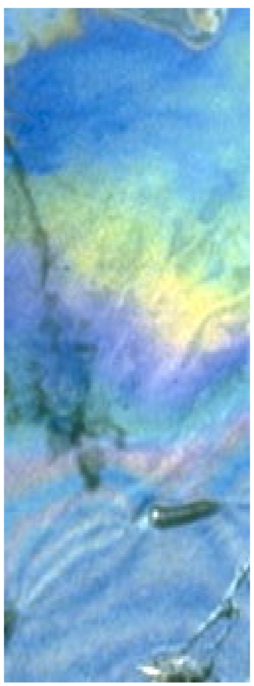


From: Ballestero et al, 1994

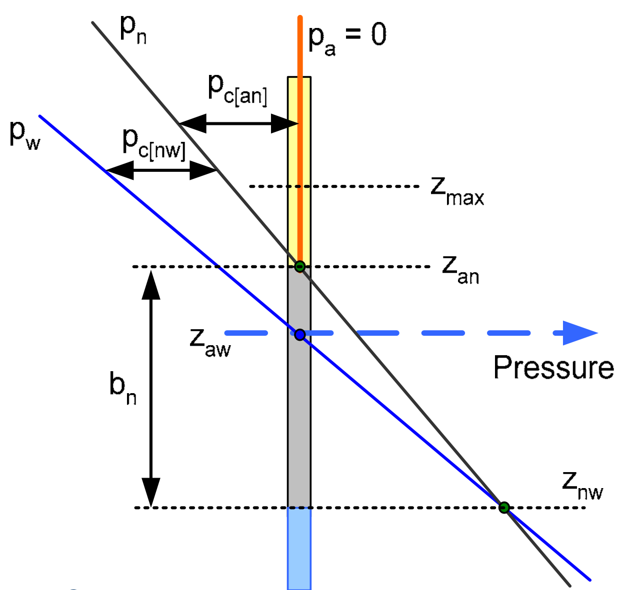


LNAPL Distribution – The “Shark Fin” distribution

LNAPL Accumulation near the Water Table



Capillary Pressures



@ z_{aw}: $p_w = 0$

@ z_{an}: $p_n = 0$

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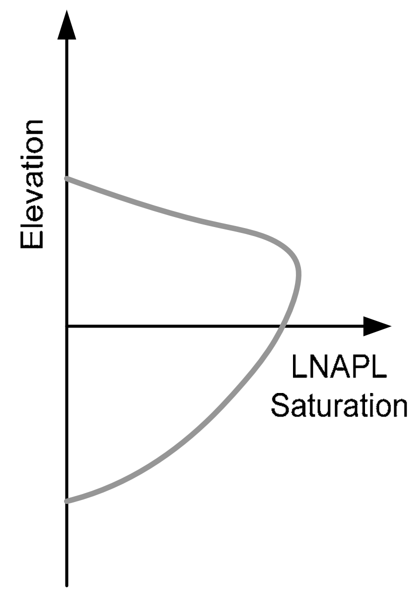
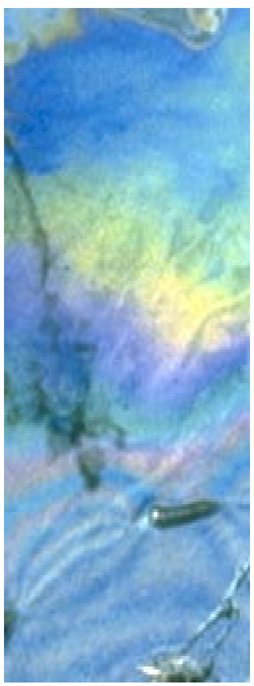
LNAPL Saturation

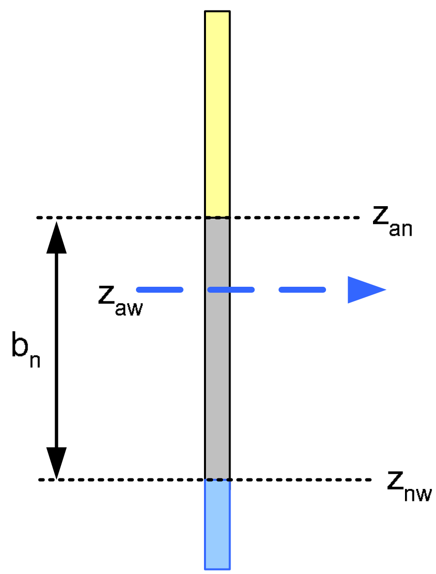


Does not include LNAPL residual saturation

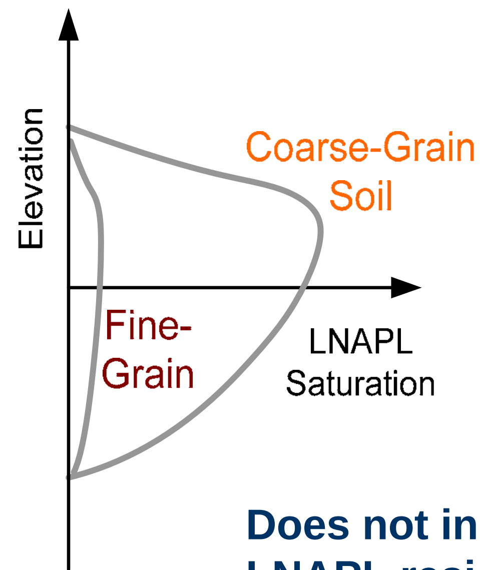
Effects of Soil Texture



Monitoring Well



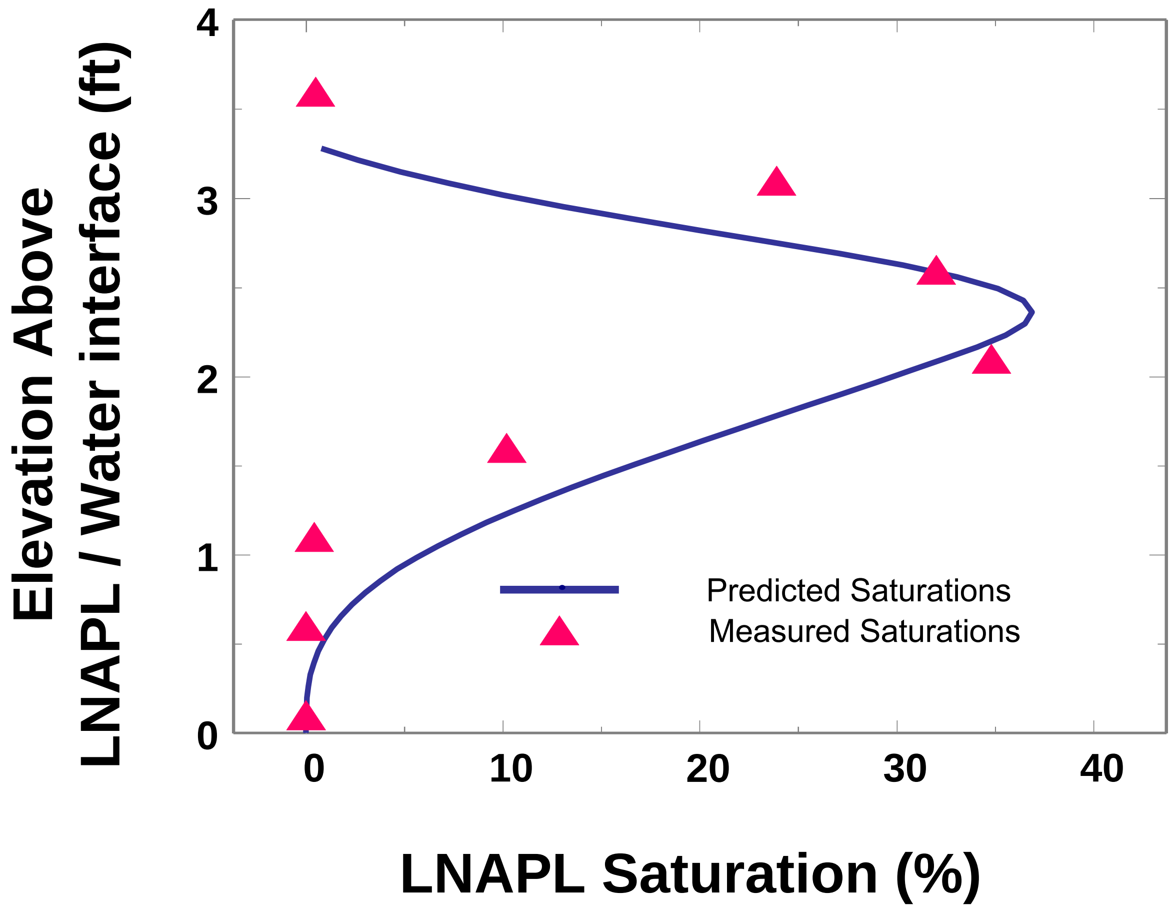
Soil Formation

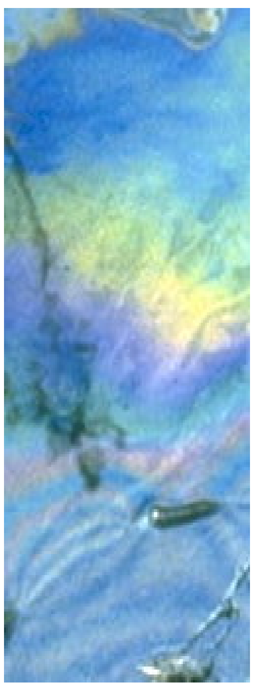


Does not include LNAPL residual saturation

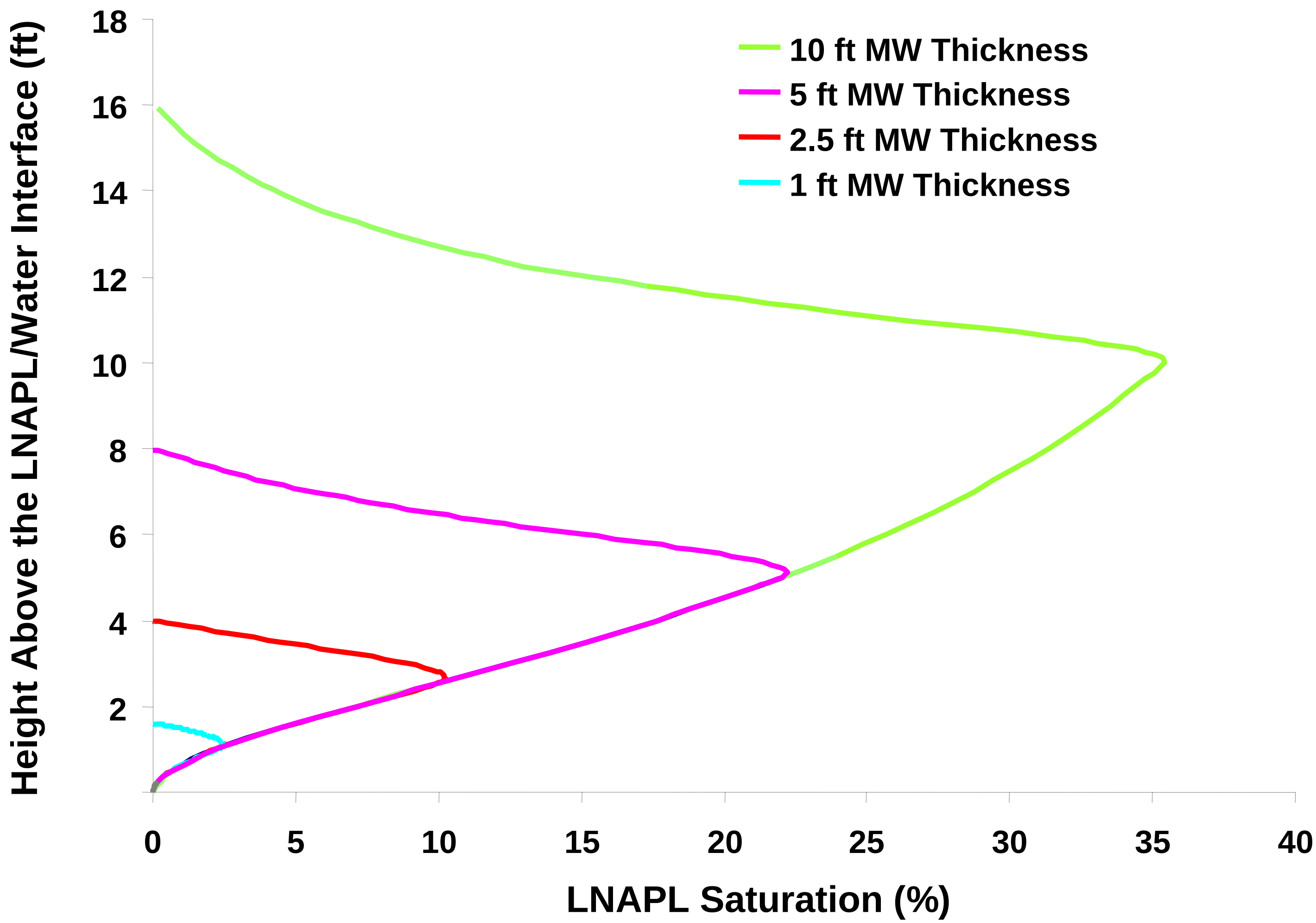
The same capillary pressure distribution (monitoring well LNAPL thickness) can correspond to greatly different LNAPL quantities being present, depending on the soil texture

Instead we consider equilibrium LNAPL saturations

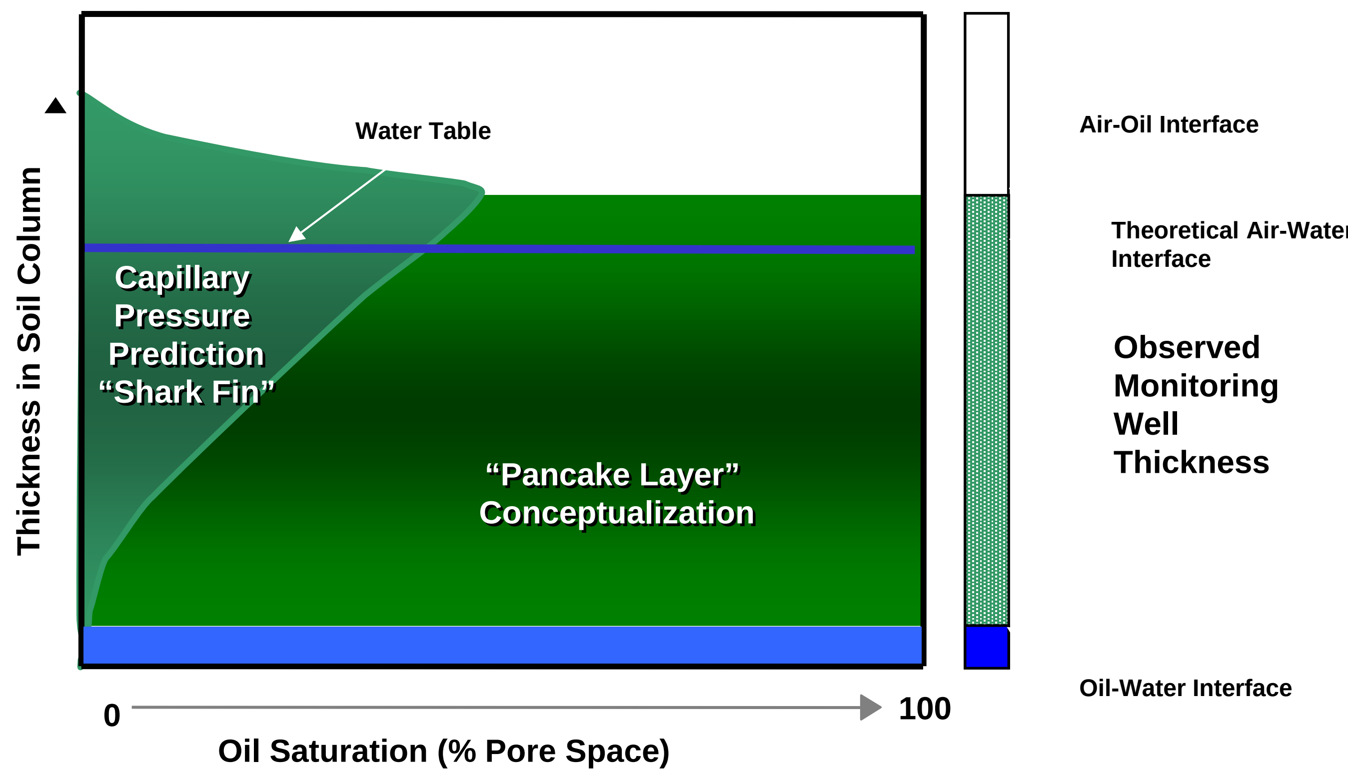




Effect of thickness in monitoring well on saturation in silty sand



Over-estimating LNAPL volumes



Key Points

- Small pores hold water tighter
- Soil will have different fluid (water) saturations at different capillary pressures
- Oil does not form the highly saturated layer (pancake) on the water table

Thank You

LNAPL **in the subsurface**